DESCRIPTION

WIRELESS SENSOR DEVICE

TECHNICAL FIELD

The present invention is directed to a wireless sensor device, and more particularly to such wireless device including a power generating element that converts an external energy into an electric power for transmitting a sensed result as a radio signal.

BACKGROUND ART

Japanese Patent Publication No. 2004-24551 discloses a self-contained sensing system including a power generating means for transmitting a sensed result. The system includes a sensor for sensing a temperature, an acceleration, or infrared ray to give a sensor signal indicative of a sensed analog value, and an A/D converter which converts the sensor signal into digital data. The digital data are processed by a microprocessor so as to be transmitted through a radio transmitter as a radio signal. A solar cell is included as the power generating means in order to supply an operating power to the A/D converter, the microprocessor, and the radio transmitter. Because of that the solar cell is not expected to constantly generate sufficient power to keep the system operative, the system requires a power regulator which enables the operation only while much power is being generated at the solar cell in order to transmit a reliable sensor result. Also because of that the radio transmitter along with the A/D converter consumes relatively large electric power, the system suggests the use of a wireless transmission technology generally known as UWB (Ultra Wide

Band) transmission which operates at a low power. However, there is still a need of minimizing the operating power in the wireless sensor system, particularly in case that the A/D converter is not necessary and only one-bit information is sufficient as the sensor result, in order to keep a reliable sensing operation over an extended period of time while relying upon the power generator of limited power generating capacity.

DISCLOSURE OF THE INVENTION

In view of the above problem, the present invention has been accomplished to provide a wireless sensor device which is less power consuming and is capable of operating over a prolonged period of time for providing a reliable sensor result. The wireless sensor device includes a sensor configured to sense a target object and provide a sensor signal of varying levels indicative of condition of the target object, a signal processing circuit configured to amplify the sensor signal and give an amplified electric analog signal, and a detection circuit configured to receive the amplified analog signal and provide a detection output (Dout) when the electric analog signal goes beyond a predetermined detection threshold. Also included in the device is a radio transmitter which is configured to transmit a radio detection signal (RS) in response to the detection output. Further, the device includes a power supply configured to provide an electric power to the signal processing circuit and the radio transmitter; and a power generating element which converts an external energy into the electric power to be accumulated in the power supply. The essential feature of the present invention resides in that a controller is included to activate the radio transmitter only in response to the detection output, permitting the radio transmitter to

generate the radio detection signal. Accordingly, the radio transmitter can be kept inactivated until receiving the detection output, thereby saving energy to prolong the operating life of the power supply, i.e., the device.

In a preferred embodiment, the radio transmitter includes a regulator, a clock, a pulse generator, and a driver. The regulator is connected to receive the electric power from the power supply and is configured to supply an operating voltage for a short time period only upon receiving the detection output from the detection circuit. The clock is activated upon receiving the operating voltage from the regulator to provide a clock signal. The pulse generator is configured to generate, based upon the clock signal, short pulses identifying the presence of the detection output. The driver is activated upon receiving the operating voltage from the regulator to radiate the short pulses as the radio detection signal through an antenna. With this arrangement, the clock and the driver are made active only upon receiving the detection output for transmitting the radio detection signal. Accordingly, the driver, which is inherently the most power consuming unit in the radio transmitter, can be kept deactivated in the absence of the detection output, whereby the radio transmitter is held in a minimum power consumption mode while not receiving the detection output, which enables to further reduce a power requirement to the device and therefore prolong the effective operating time.

In order to further save the energy on the side of the signal processing circuit, the controller may be configured to give a sleep mode of operating the signal processing circuit at a reduced power, and to shift the sleep mode to a normal mode for reliable detection once there is acknowledged a slight sign leading to the detection output. In the normal mode, the signal processing

circuit operates at a rated power to obtain the electric signal (Vout) of rated amplitude proportional to the rated power. In the sleep mode, the signal processing circuit operates at the reduced power to obtain the electric signal (Vout) of low amplitude proportional to the reduced electric power. In this connection, the detection circuit is configured to have a wake-up threshold which is lower, i.e., stricter than the detection threshold. The controller is designed to switch the normal mode to the sleep mode when the electric signal (Vout) of rated amplitude becomes lower than the detection threshold, and to keep the sleep mode until the electric signal of the low amplitude goes beyond the wake-up threshold. The detection output (Dout) is given when the electric signal (Vout) of rated amplitude goes beyond the detection threshold in the normal mode.

The sensor may be an infrared ray sensor for detection of a motion of the target object by monitoring a critical change of infrared ray emitted from the target object, for example, human body. The infrared ray sensor is configured to provide the sensor signal which varies in positive or negative directions in response to the motion of the target. In this instance, the detection circuit is configured to have a threshold selector which provides a detection range (A1-A2) defined by upper positive and lower negative ones of said detection threshold, and also a wake-up range (B1-B2) defined by upper positive and lower negative ones of the wake-up threshold. The detection circuit includes a comparator unit which receives the detection range and the wake-up range selectively from the threshold generator for comparison of the analog signal with the selected one of the ranges. The comparator unit generates a first signal either when the electric signal (Vout) of rated amplitude goes beyond the detection range or when the

electric signal (Vout) of low amplitude goes beyond said wake-up range, and otherwise generating a second signal. The controller is configured to select the detection range in response to the first signal, and select the wake-up range in response to the second signal. The detection circuit provides the detection output only upon seeing the first signal in the normal mode. Accordingly, the sensor device can successfully detect the motion of the target object using the infrared ray sensor, while saving the energy.

The detection circuit may include an output provider which is configured to generate the detection output (Dout) when receiving the first signal from the comparator unit at an input of said output provider. The input is connected to the comparator unit through a switch which is controlled by the controller to close only in response to the first signal. Thus, the output provider is protected from generating a false detection signal in the absence of the first signal, thereby improving detection reliability.

Further, the controller is connected to monitor a level of the electric power accumulated in the power supply for keeping the normal mode and disabling the sleep move while the electric power is higher than a predetermined power level. That is, while sufficient power is available, the detection circuit is kept free from a shifting between the modes, and therefore can be free from being influenced by unstable circuit operation which might appear during the transient mode shifting, assuring a reliable detection.

Still further, the sensor may be defined by a photovoltaic cell which senses an illumination level on one hand and which converts light into electrical energy for accumulating electric power in the power supply.

These and still other advantageous features of the present invention will

become more apparent from the following detailed description of the preferred embodiments when taken in conjunction with the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a sensor device in accordance with a preferred embodiment of the present invention;

FIG. 2 is a circuit diagram of a detection circuit employed in the above device;

FIG. 3 is a graph illustrating an operation of the device;

FIG. 4 is a block diagram of a sensor device in accordance with another preferred embodiment of the present invention; and

FIG. 5 is a block diagram of a sensor device in accordance with a further preferred embodiment of the present invention.

BEST MODE FOR CARRYING OUT THE INVENTION

Referring now to FIG. 1, there is shown a sensor device in accordance with a preferred embodiment of the present invention. The device is specifically arranged to detect a human motion, i.e. whether the human comes into or out of a surveillance area by use of an infrared ray sensor which generates an electric sensor signal responsive to infrared radiation from the human, although the present invention should not be limited to this particular instance. The infrared ray sensor **10** generates the sensor signal which varies in positive and negative directions in response to the motion of the human coming into and out of the surveillance area.

The device includes a signal processing circuit **20** which processes the sensor signal to give an amplified analog signal, and a detection circuit **50** which

compares the analog signal with predetermined criteria to provide a detection output according to the comparison result. The device further includes a radio transmitter **90** which, in response to the detection output (Dout), generates and radiates a radio detection signal (RS) thorough an antenna **97** such that a receiver (not shown) acknowledge the detection result. A power supply **100** is included in the device to provide an electric power to the signal processing circuit **20**, the detection circuit **50**, and the radio transmitter **90**. Also included in the device is a power generating element **110** which converts an external energy into the electric power to be accumulated in the power supply **100**. The power generating element **110** is realized in this embodiment by solar cell which converts the light into the electric power. A controller **120** is provided to give a consistent detection result to the radio transmitter **90** as well as to save the energy in the absence of a critical condition sensed by the sensor, the details of which will be discussed later.

The signal processing circuit **20** is composed of a current-voltage converter **30** converting the current signal, i.e., the sensor signal output from the sensor **10** into a corresponding voltage signal, and a voltage amplifier **40** which amplifies the voltage signal into the amplified analog signal (Vout) of which amplitude varies depending upon an amplification factor instructed from the controller **120**. In this connection, the controller **120** provides a normal mode of operating the signal processing circuit **20** at a rated power, and a sleep mode of operating the signal processing circuit **20** at a reduced power for saving the energy. In the normal mode, the signal processing circuit **20** operates at a high amplification factor and therefore at a high power consumption to provide the analog signal (Vout) of rated amplitude. In the sleep mode, the signal

processing circuit **20** operates at a low amplification factor and therefore at a low power consumption to provide the analog signal (Vout) of reduced amplitude.

As shown in FIG. 2, the detector circuit **50** has a comparator unit **70** composed of comparators **71** and **72** in order to compare the analog signal (Vout) from the signal processing circuit **20** selectively with a wide detection range (VA1 to VA2) and a narrow wake-up range (VB1 to VB2) respectively defined by predetermined thresholds which are in turn defined respectively by divided voltages from a voltage dividing network **52**. The detector circuit **50** also includes a selector **60** which is composed of switches **61** to **64** in order to give the divided voltages (VA1 and VB1) selectively to non-inverting input of the comparator **71**, and give the divided voltages (VA2 and VB2) selectively to the inverting input of the comparator **72**. The selector **60** is controlled by the controller **120** to select the detection range (VA1 to VA2) given to the comparator unit **70** in the normal mode, and select the wake-up range (VB1 to VB2) given to the comparator unit **70** in the sleep mode. The inverting input of the comparator **71** and the non-inverting input of the comparator **72** are commonly coupled to receive the analog signal (Vout). The outputs respectively from the comparators **71** and **72** are fed into an AND-gate **73** which provides a logical product of L-level output, which is referred to as a first signal in the following description, when the signal (Vout) goes beyond the detection range (VA1 to VA2) in the normal mode or beyond the wake-up range (VB1 to VB2) in the sleep mode, as shown in FIG. 3 Otherwise, i.e., when the signal (Vout) is within the detection range in the normal mode or the wake-up range (VB1 to VB2) in the sleep mode, the AND-gate **73** provides a H-level output, which is referred to as a second signal. The controller **120** is connected to receive the output from the AND-gate **73** to

select the normal mode in response to the first signal, and shift the normal mode to the sleep mode upon receiving the second signal in the normal mode for energy savings. When the signal (Vout) of the reduced amplitude goes beyond the wake-up range (VB1 to VB2) in the sleep mode, the controller **120** receives the first signal from the AND-gate **83**, thereby selecting the normal mode in order to compare the signal (Vout) with the detection range (VA1 to VA2).

The AND-gate **73** is connected through a switch **76** to an output provider **80** which responds to generate the detection output (Dout). The switch **76** is controlled by the controller **120** to close only in response to the first signal, i.e., only when the signal (Vout) goes beyond the detection range (VA1 to VA2) in the normal mode. Otherwise, the switch **76** is kept open such that the output provider **80** gives no detection output. The output provider **80** includes a transistor **81** having a drain connected to a reference voltage source Vdd, and a source connected to an output terminal of the detector unit **50**. A gate of the transistor **81** defines an input of the output provider **80** which is connected to receive the output from the comparator unit **70** through the switch **76**. A pull-up resistor **82** is connected across the gate-drain path of the transistor **81** so that the transistor **81** generates the detection output (Dout) upon receiving the first signal (Vout), i.e., the H-level output from the AND-gate **73**. In the absence of the first signal (Vout) fed to the gate of the transistor **81**, it refrains from generating the detection output (Dout). The switch **76** is inserted between the AND-gate **73** and the gate of the transistor **81** in order to avoid a possibility that transistor **81** generates the detection output in the absence of the first signal. Also the switch **76** is controlled by the controller **120** to open only for a short time immediately after the controller **120** shifts the sleep mode to the normal mode and vice versa,

thereby preventing the generation of the detection output (Dout) when the signal of reduced amplitude goes beyond the wake-up range in the sleep mode, and like erroneous generation of the detection output which might otherwise occur due to an abrupt voltage change possibly seen in the circuit during the transition between the two modes. Further, the output provider **80** may be configured to include a noise filter which cancels the first signal generated in the wakeup mode or the like noises even when they pass through the switch **76**.

Turning back to FIG. 1, the radio transmitter **90** is configured to include a regulator **92**, a clock **93**, a pulse generator **94**, and a driver **96**. The regulator **92** is configured to supply a stable operating voltage V_{REG} to the clock **93** and the driver **96** only for a short time period each upon receiving the detection output (Dout), i.e., recognition of the human presence. That is, the regulator **92** is triggered by the detection output (Dout) to supply the operating voltage V_{REG} using a power supplied from the power supply **100**, and otherwise supply no operating voltage at all. Upon receiving the operating voltage V_{REG}, the clock **93** is activated to provide a clock signal to the pulse generator **94** which generates, based upon the clock signal, short pulses identifying the presence of the detection output with or without an address of the sensor device. The driver **96**, which is activated by the operating voltage V_{REG} from the regulator **92** to receive the short pulses from the pulse generator **94** and radiate the short pulses as the radio detection signal (RS) through an antenna **97**. The radio transmitter **90** has an power input **91** through which the electric power is constantly supplied to the regulator **92** and the pulse generator **94** so that the regulator **92** and the pulse generator **94** are ready for activating the clock **93** and the driver **96** in prompt response to the detection output (Dout) from the detection circuit **50**.

The driver **96** includes an amplifier and consumes more power than any other components of the radio transmitter **90**, while the pulse generator **94** and the regulator **92** in its idle mode of providing no operating voltage consume less electric power. Accordingly, in the absence of the detection output (Dout), the radio transmitter **90** consumes less power and assures prolonged operating life of the sensor device. Further, it is noted that the regulator **92** supplies the operating voltage VREG only for the short time period each time it receives the detection output (Dout), the radio transmitter **90** is reset into a low power consumption mode immediately after transmitting the radio signal (RS). The radio signal is received at a nearby receiver for recognition of the human presence or the detected result.

The pulse generator **92** is configured to constitute a ultra wide band transmission (UWB) system, a wireless communication technology that does not use a carrier wave, but rather a train of very short pulses in the order of hundreds of picosecond range. The system therefore requires only a small electric power at the instant of transmitting the data. In the present embodiment, the data is basically composed of one-bit signal identifying whether or not the detection output (Dout) is H-level, requiring only a very short transmission time. For example, when the radio transmitter **90** transmits the radio detection signal (RS) per ten seconds, each transmission is completed within one millisecond at an average operating current of 2 mA, consuming only 0.2 μA. In this manner, the radio transmitter **90** of the UWB system can operate in a low energy consumption mode, and therefore reducing the power requirement of the sensor system.

The power supply **100** is configured to have a voltage booster **102** which amplifies the voltage supplied from the solar cell **110**, and a capacitor **104**

accumulating the amplified voltage for supplying the resulting electric power to the signal processing circuit **20**, the detection circuit **50**, and the radio transmitter **90**. For example, the above circuits **20**, **50**, the radio transmitter **90**, and the voltage booster **102** are each designed to operate at an average consumption current of 5 μA and to require a normal operative voltage of 4V and a minimum operating voltage of 2V. In this instance, the entire system of the sensor device consumes 10 μW to 20 μW. Provided that the voltage booster **102** sees no electric conversion loss, the solar cell **110** is required to have a power generating capacity of 20 μW or more, which is easy to be accomplished only with the use of an amorphouse photovoltaic cell having an effective surface area of 3 cm^2 at an illumination of about 200 lux or more. Thus, the sensor device can permit the use of small-sized solar cell, and is therefore assembled into a small package.

FIG. 4 illustrates a sensor device in accordance with a second embodiment of the present invention which is identical to the above embodiment except that the controller **120** monitors the power level being generated at the solar cell **110** for comparison with a predetermined power level. The like parts are designated by like reference numerals, and no duplicate explanation is repeated. As long as the power level is higher than the predetermined power level, the controller **120** responds to fix the normal mode, i.e., disable the sleep mode, so as to keep the entire system awake for immediate detection. Otherwise, the controller **120** allows the shifting between the normal mode and the sleep mode for energy saving.

FIG. 5 illustrates a sensor device in accordance with a third embodiment of the present invention which is identical to the first embodiment except that the sensor **10** is prepared as an illumination sensor made of a photovoltaic cell. In

this embodiment, the photovoltaic cell **10** is commonly utilized as the power generating element **110**. Like parts are designated by like reference numerals, and no duplicated explanation is repeated here.

Although the above embodiments illustrate the sensors for detection of the human motion and for detection of the illumination level, the present invention should not be interpreted to be limited to the particular embodiments and can encompass any other sensor, such as a temperature sensor, vibration sensor or the like which gives the detection output when the sensed parameter exceeds a predetermined threshold or goes beyond a threshold range. Likewise, the power generating element may be anyone that converts the external energy, such as thermal or mechanical energy into the electric power.